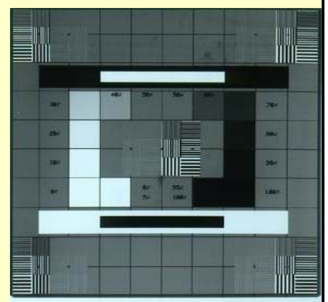
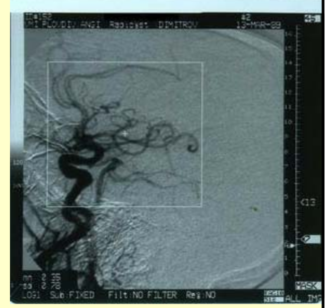
Digital Radiography Image Parameters
SNR, MTF, NPS, NEQ, DQE





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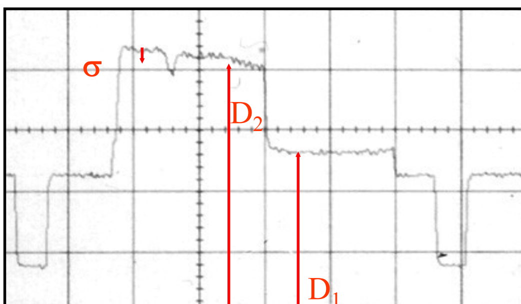


I – Intensity

D – Density

E - Exposure

Subject Contrast

$\Delta C = I_2 - I_1$

Visual contrast

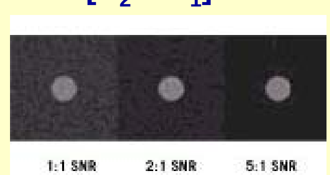
$\Delta C = \log I2 - \log I1$

Radiographic contrast

$\Delta C = [D_2 - D_1]/D_1$

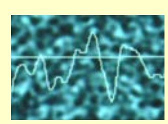
Signal-to-Noise Ratio (SNR): S/N

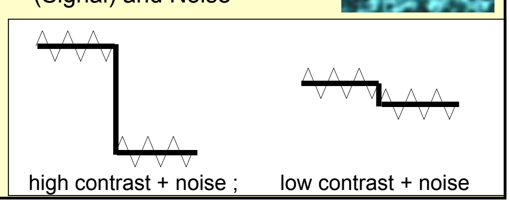
$\Delta C = [D_2 - D_1]/\sigma$

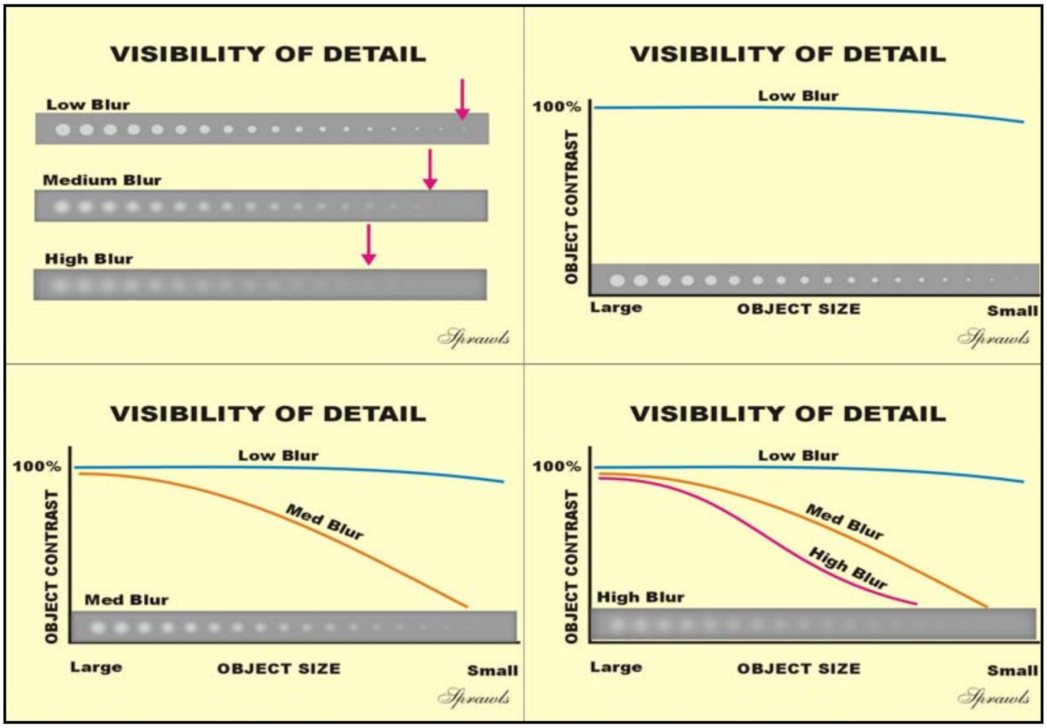


SNR

Limiting Contrast (Signal) and Noise






VISIBILITY OF DETAIL
Low Blur
Medium Blur
High Blur
Sprawls
VISIBILITY OF DETAIL
Low Blur
100%
OBJECT CONTRAST
Large
OBJECT SIZE
Small
Sprawls
VISIBILITY OF DETAIL
100%
Low Blur
Med Blur
OBJECT CONTRAST
Med Blur
Large
OBJECT SIZE
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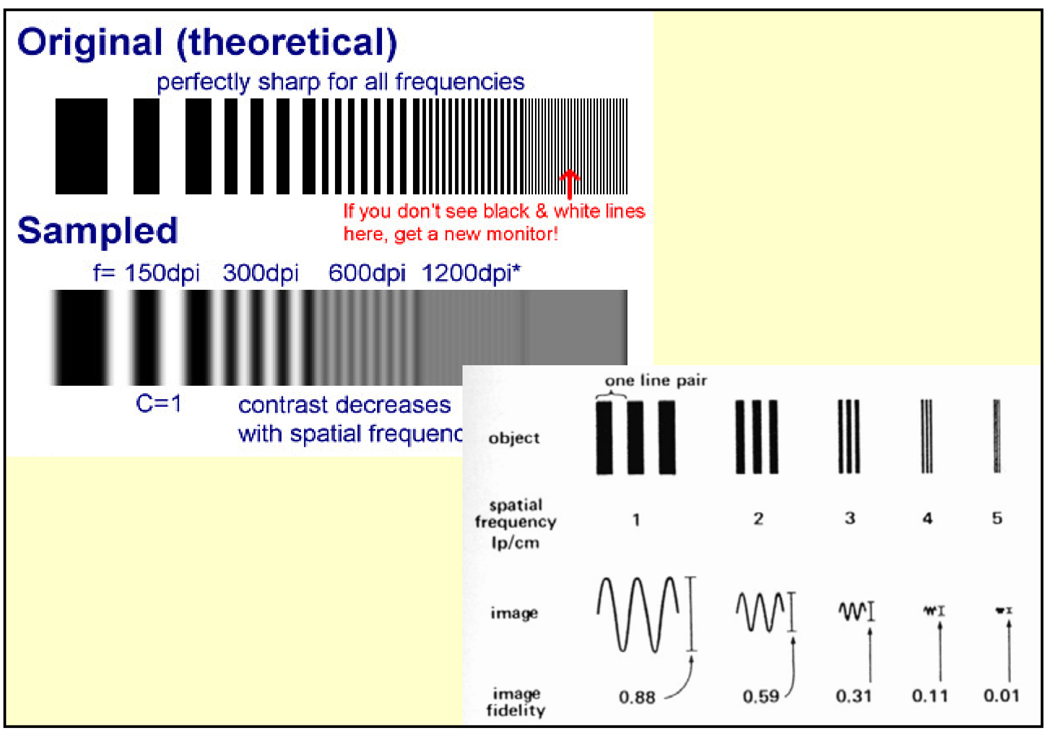
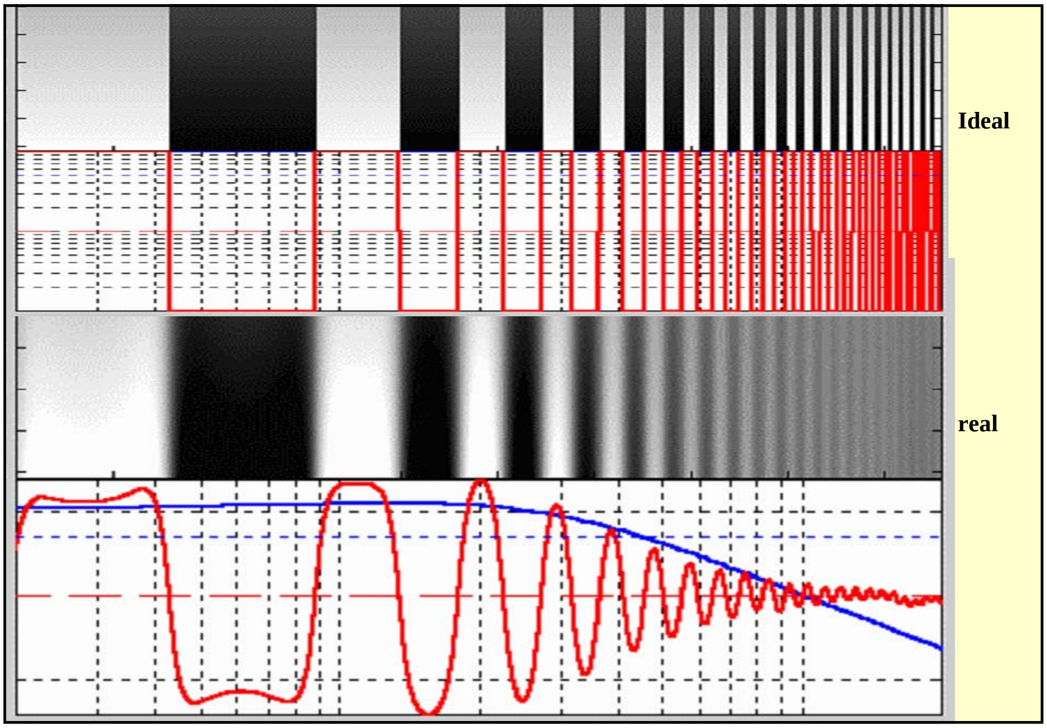
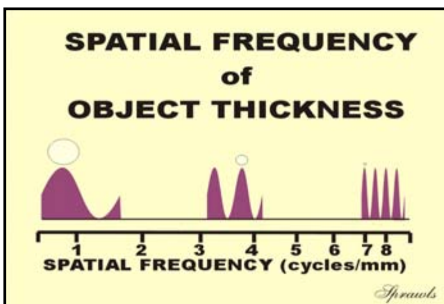
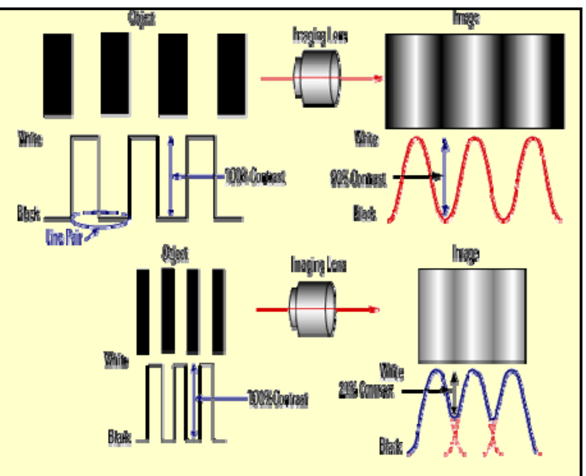
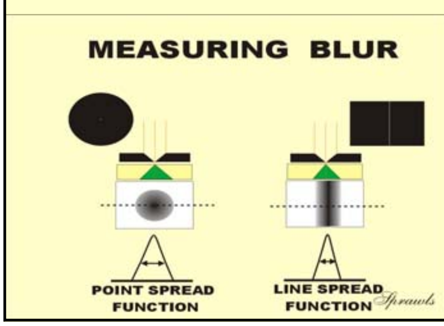
Large
OBJECT SIZE
Small
Sprawls


Original (theoretical)
perfectly sharp for all frequencies
If you don't see black & white lines here, get a new monitor!
Sampled
f= 150dpi 300dpi 600dpi 1200dpi*
C=1
contrast decreases
with spatial frequenc
one line pair
object
spatial frequency lp/cm
1
2
3
4
5
image
image fidelity
0.88
0.59
0.31
0.11
0.01

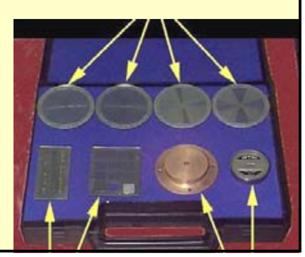


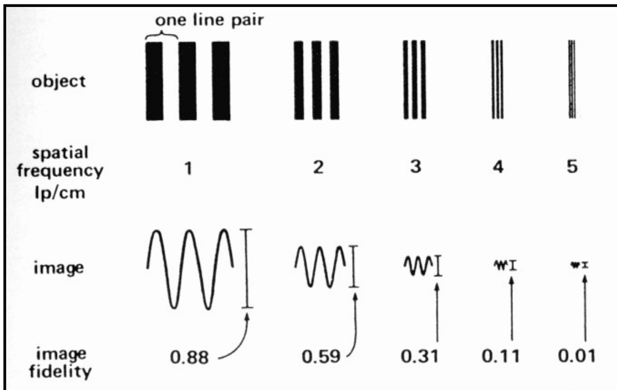






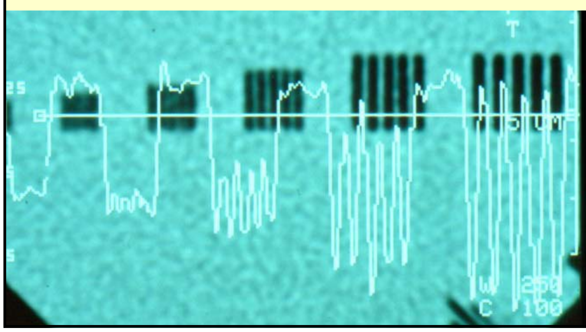
Spatial frequency
(Line pair per mm)
and
Blur measurement
(the problem in medical imaging is larger as the objects are not with sharp edges, what changes the peripheral absorption μd)

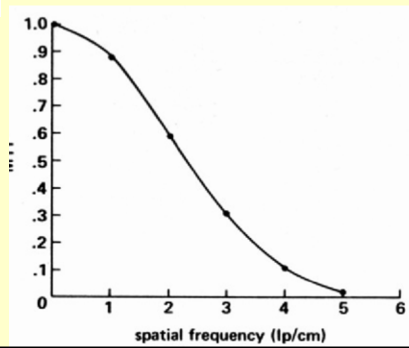


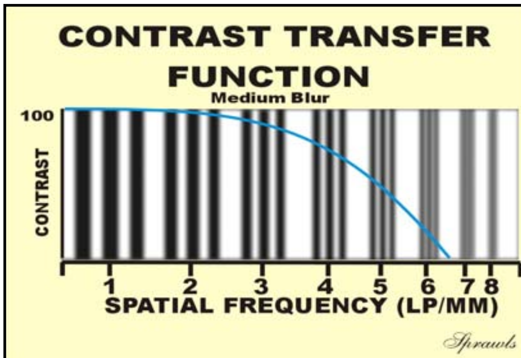


Contrast Transfer Function Concept

10% - cut-off frequency (lim. sp. res.)





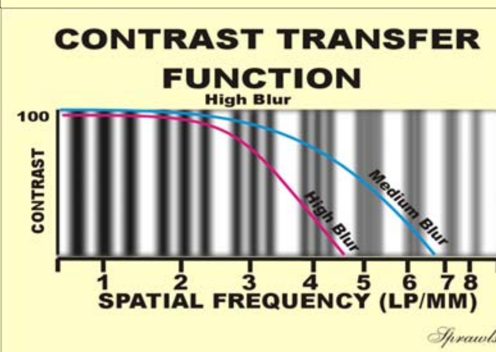


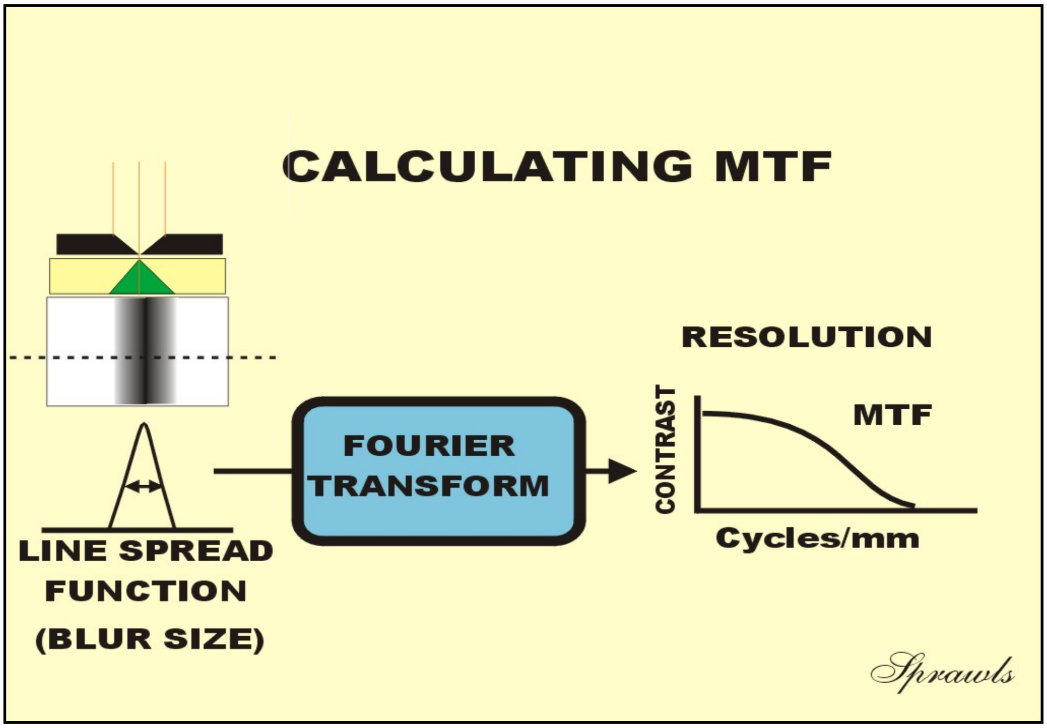
Example from the image >>>

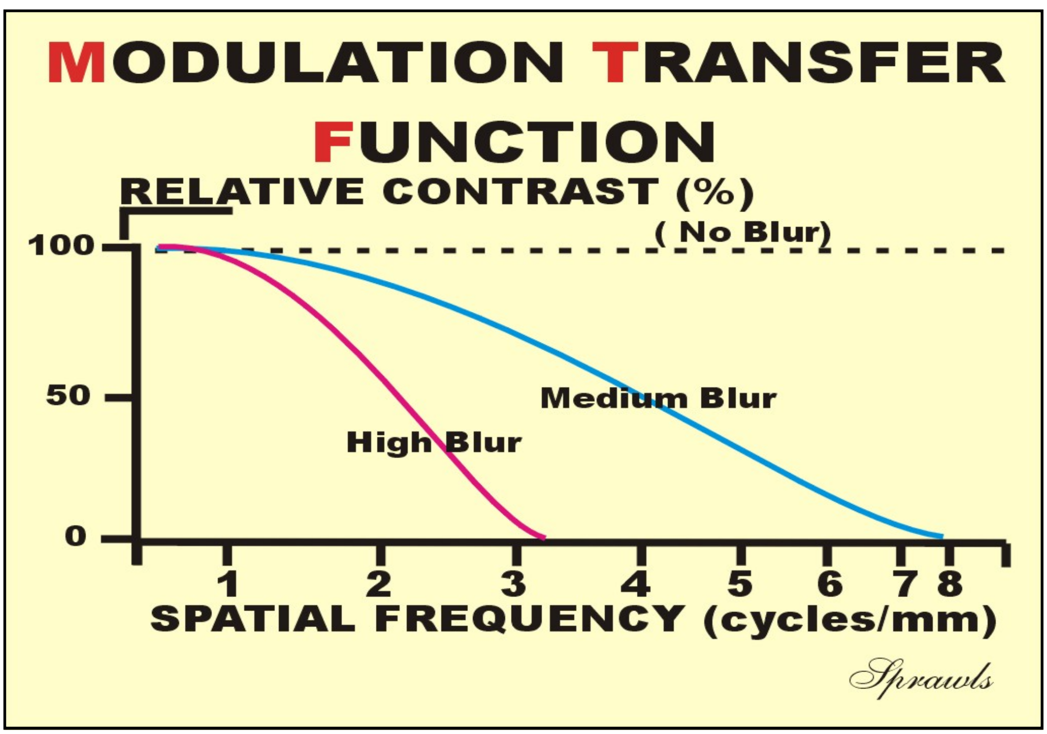
At high blur limiting Sp. Resolution is 4.5 lp/mm

In this case the smallest object to be seen is =

= 1/(2 x 4.5) = 0.11mm **[1/(2 x sp.res)]**

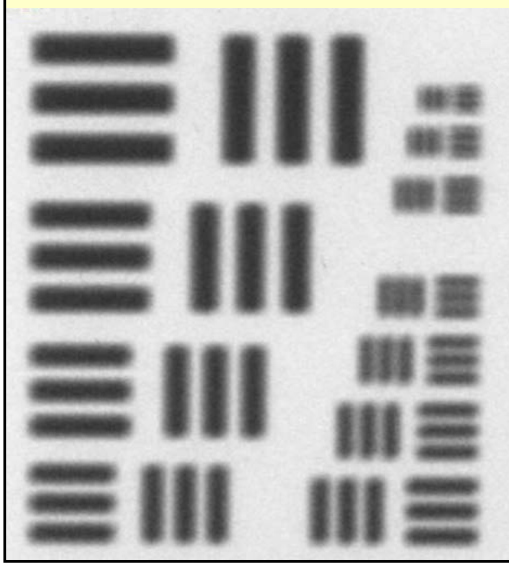


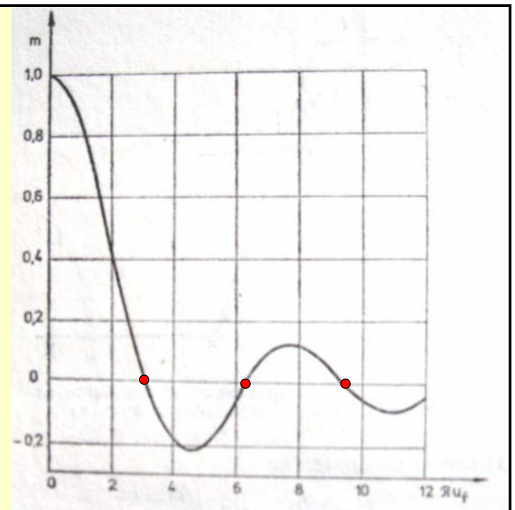

CALCULATING MTF
RESOLUTION
CONTRAST
MTF
FOURIER
TRANSFORM
Cycles/mm
LINE SPREAD
FUNCTION
(BLUR SIZE)
Sprawls


MODULATION TRANSFER
FUNCTION
RELATIVE CONTRAST (%)
(No Blur)
100
50
0
Medium Blur
High Blur
1
2
3
4
5
6
7
8
SPATIAL FREQUENCY (cycles/mm)
Sprawls

Modulation Transfer Function

MTF=(recorded signal f)/(origin. signal f);
also MTF(f) = | FT{LSF(x)} |





MTF~m = $\sin \pi . u_f / \pi . u_f$,where

u_f = f/L * (M-1)/2M ,where

M-magnif.; f – focal spot; L – period of the structure (~ to spatial frequency)

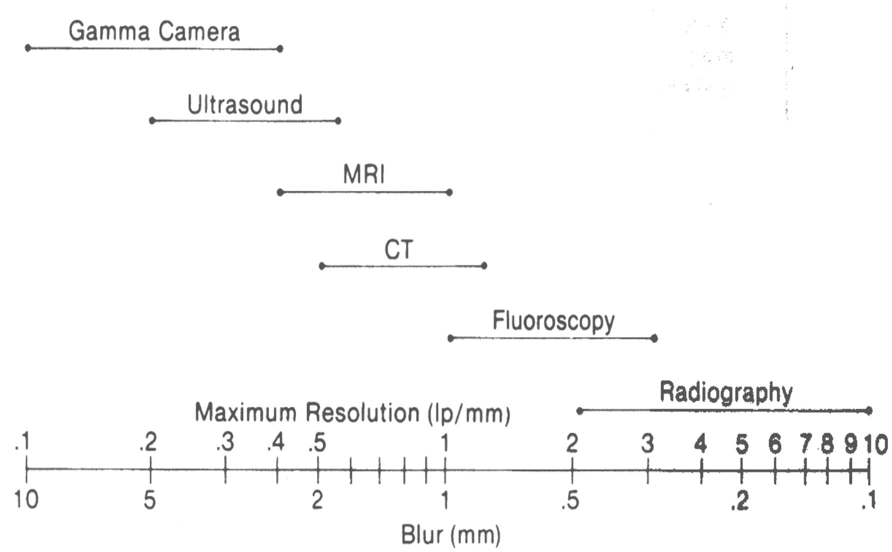
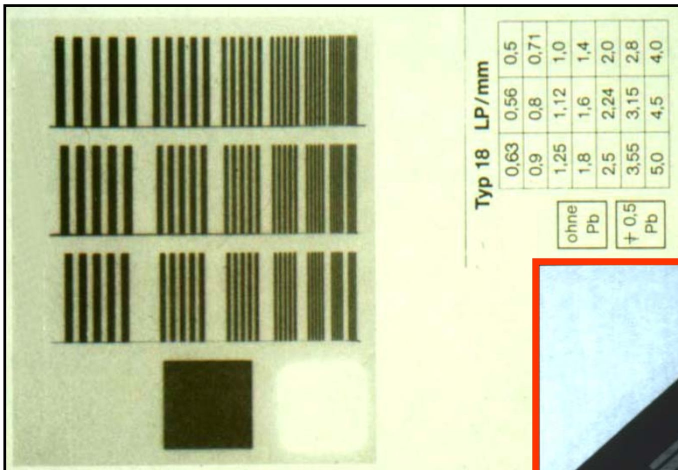
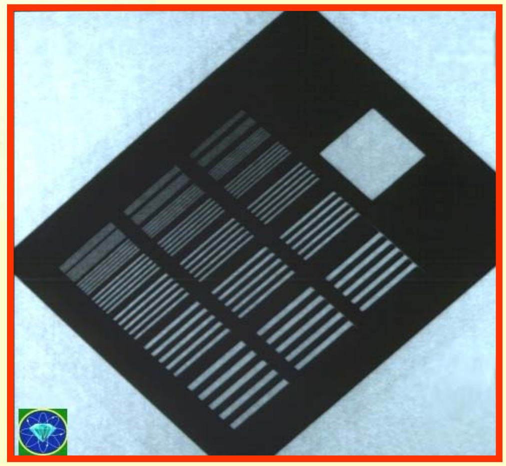


Figure 18-10 Comparison of Blur and Resolution Values **for the Different Imaging** Methods



Assessment of
Spatial Resolution (Lp/mm)



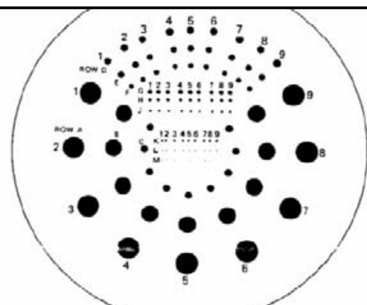
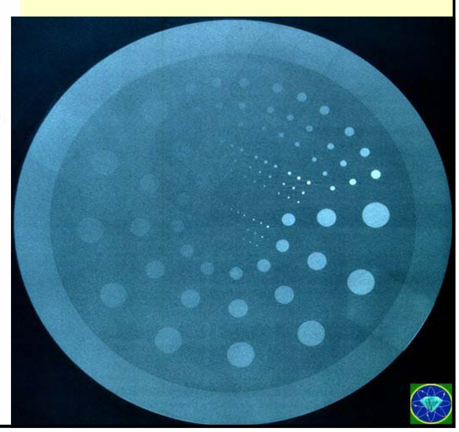


Figure 5. Test Object TO-7

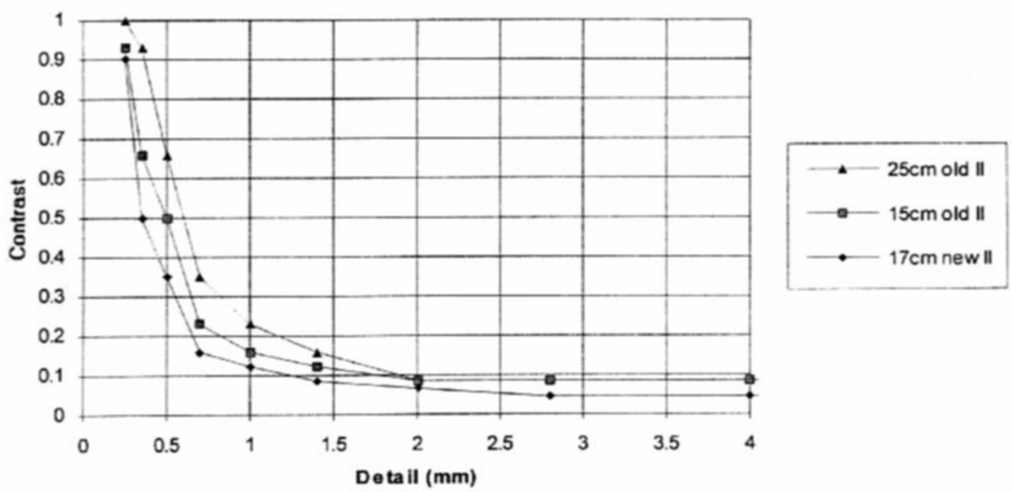
Table 3. Description of Test Object TO-7
X-ray contrasts for each row (A to M) containing 9 discs

Row	Dia. mm	Disc number 1	2	3	4	5	6	7	8	9
A	11.1	.16	.125	.088	.063	.044	.022	.016	.011	.0075
B	7.9	.16	.125	.088	.063	.044	.022	.016	.011	.0075
C	5.6	.16	.125	.088	.063	.044	.022	.016	.011	.0075
D	4.0	.23	.16	.125	.088	.063	.044	.022	.016	.011
E	2.8	.23	.16	.125	.088	.063	.044	.022	.016	.011
F	2.0	.23	.16	.125	.088	.063	.044	.022	.016	.011
G	1.4	.50	.34	.23	.16	.125	.088	.063	.044	.022
H	1.0	.50	.34	.23	.16	.125	.088	.063	.044	.022
J	0.7	.50	.34	.23	.16	.125	.088	.063	.044	.022
K	0.5	.95	.68	.50	.34	.23	.16	.125	.088	.063
L	0.35	.95	.68	.50	.34	.23	.16	.125	.088	.063
M	0.25	.95	.68	.50	.34	.23	.16	.125	.088	.063

Assessment of
Contrast Resolution
(C/D)



Typical Contrast/Detail diagram for the *Leeds TO 10* phantom for various II filed sizes (old and new II)



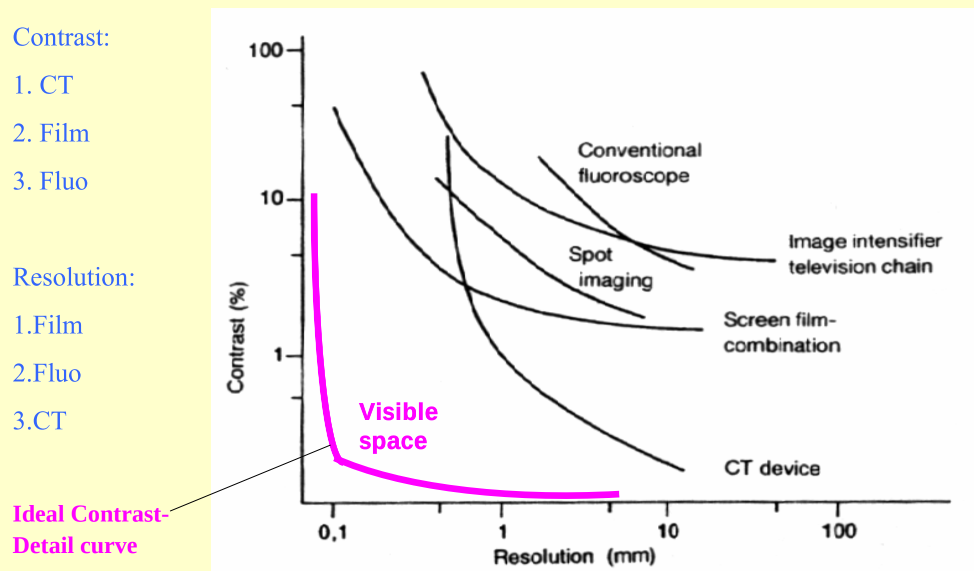
Contrast and Resolution of various X-ray detectors and methods

Contrast:

1. CT
2. Film
3. Fluo

Resolution:

1. Film
2. Fluo
3. CT



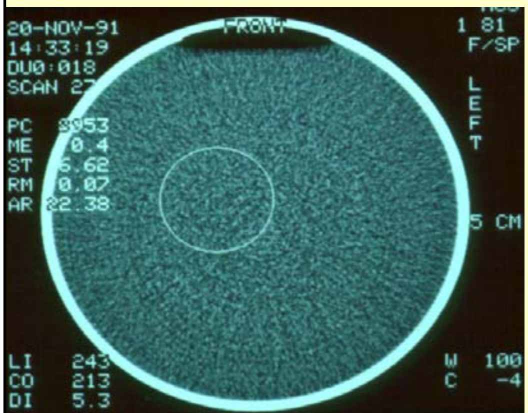


Image Quality in Digital Imaging

* Noise in the image:
superposition of a meaningless set of signals over meaningful signals

There are two primary contributions to noise; the quantum noise from statistical fluctuations in the number of X-ray quanta detected per unit area (quantum mottle) and the noise arising from variations in the imaging system

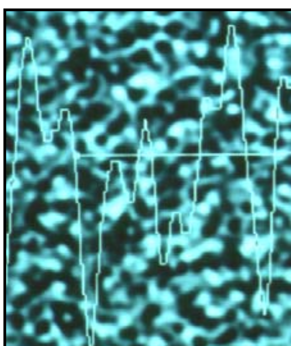
CT noise (on image) is measured as standard deviation of mean CT values (it varies most often from 1 to 10 CT)

- Standard deviation (noise):

$$\sigma = [\Sigma(CT_i - CT_{mean})^2 / (n-1)]^{1/2}$$

Noise is the main limitation of contrast resolution

- Min. contrast > noise level (HU)

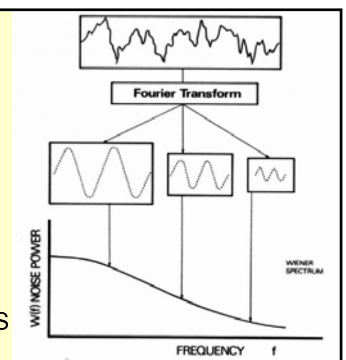


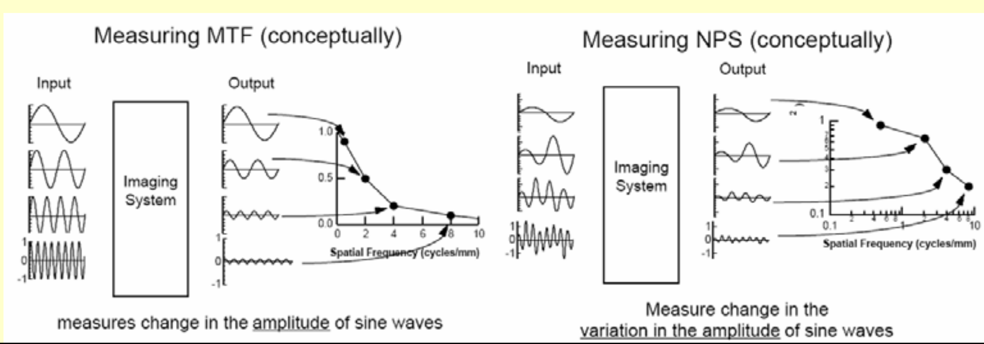
Noise Power Spectrum

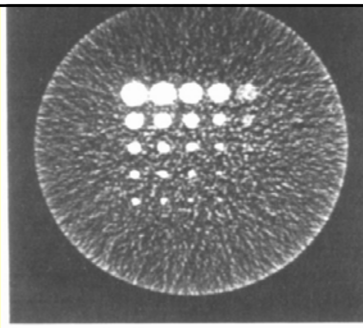
(Wiener noise spectrum)

•NPS takes both the magnitude and texture of noise into account

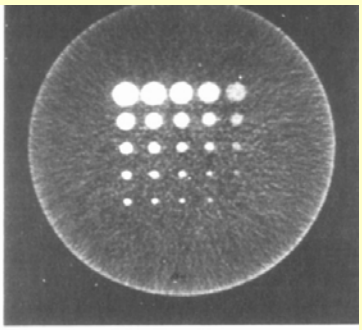
The main problem in using the NPS to determine noise properties in an imaging system is that the method requires averages (integrals) over an infinite data set to obtain the true NPS but we have finite set of data.







10 mGy



80 mGy

Quantum Detection Efficiency (QDE)

i.e. Measurable Detection Efficiency

If a square detector records N X-ray quanta, the noise *per pixel* will be: $\sigma \sim \sqrt{N}$,
where σ is the standard deviation (or noise).
hence the variance $\sigma^2 = N$

A human observer perceives *Relative noise* or Coefficient of Variation (COV) = $\sigma/N = 1/\sqrt{N}$

The Signal-to-Noise Ratio (SNR) will be
$SNR = N/\sigma = \sqrt{N}$

We can increase the image quality (SNR) by increasing the number of X-ray quanta (N), but this increases the Dose. We need 4 times higher dose (N) to increase twice the SNR.

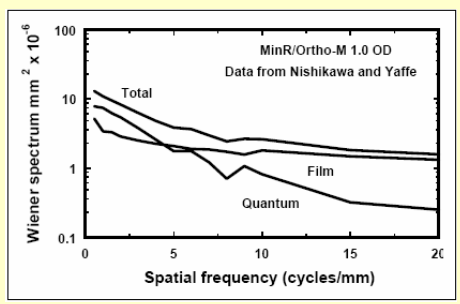
A real detector can not record all X-ray quanta, hence $QDE = N_{detected} / N_{incident}$, thus

$SNR_{real} = \sqrt{N_{detected}} = \sqrt{(QDE \text{ x } Nincident)}$

Different elements of the Imaging chain contribute to the overall NPS

The Normalised NPS (NNPS), is related to the large area signal (LAS) *i.e.* the average pixel value in the image.

$$NNPS = \frac{NPS}{LAS^2}$$



The Noise Equivalent Quanta (NEQ) is a measure of the signal to noise ratio (SNR : **S/N**) of an imaging system.

$$SNR = \frac{N}{\sqrt{N}}$$

NEQ is the number of quanta N incident on an *ideal detector* that would give the same output SNR as a non-ideal detector (noise $\sigma \sim \sqrt{N}$, N- incident photons: signal)

$$NEQ = \left(SNR^2\right)_{out}$$

An ideal detector will detect all incident quanta, will add no noise and has no blur – i.e. we have only signal - **N**.

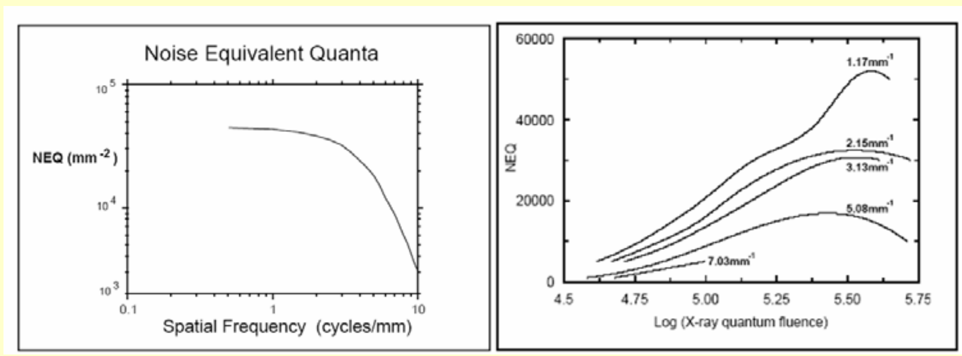
NEQ can be considered as the number of quanta used in acquiring an image at a particular dose level, as a function of spatial frequency.

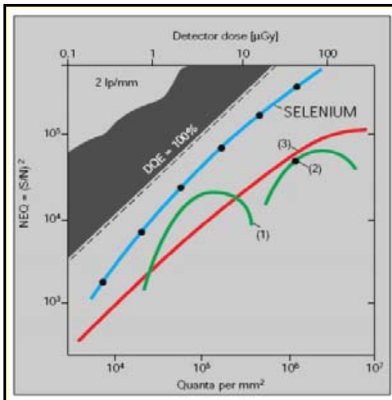
$$SNR_{out} = \frac{MTF(f)}{NPS(f)}$$

NEQ drops off rapidly with increasing spatial frequency because both MTF and NNPS drop off with increasing spatial frequency.

NEQ is often plotted against quantum fluence. This shows well the relationship between x-ray dose and the image quality of a system.

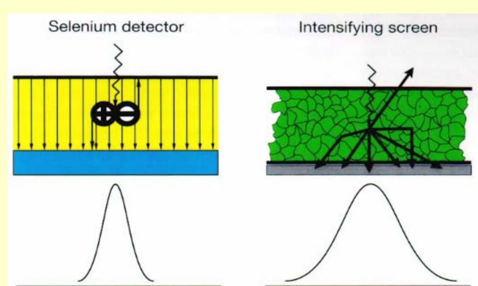
The graph on the right is for a screen-film system and it is clear that a specific dose is required to achieve the best NEQ.





NEQ as a function of detector exposure taken at 2 lp/mm

Selenium detector (blue) is compared to (1), (2) - Conventional Screen-film combinations and (3) - ST III storage phosphor screen



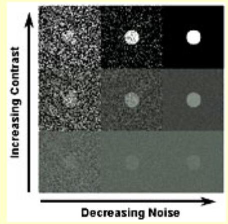
Selenium detector has smaller blur due to the specific technology

NEQ is useful for measuring how efficient the imaging system is with respect to the incident X-ray quanta used in image formation and can directly describe the potential of the actual image. However when comparing the ideal and non-ideal detector there are losses arising from X-ray quanta not being absorbed, increased noise being introduced by the system during the conversion process, and additional noise independent of the X-ray quanta being introduced by the system. The efficiency can be calculated by comparing the NEQ to the quantum fluence of the incident radiation. This leads to DQE.

The Detective Quantum Efficiency (DQE) is effectively a measure of how well the x-rays are used in an imaging system (the efficiency of converting input quanta to signal or the efficiency of preserving the SNR).

DQE is influenced by the MTF, readout and quantum noise, and detection efficiency in an imaging system.

DQE is defined as the ratio of the squared SNR at the output of the detector to the SNR of the input. DQE=1 means that all produced quanta are used to make the image without any noise



DQE can also be expressed in terms of measurable quantities, including MTF and NPS, where

q_o is the mean incident fluence and G is the system gain.

$$DQE = \frac{\left(SNR^2\right)_{out}}{\left(SNR^2\right)_{in}} = \frac{NEQ}{N}$$

$$DQE = \frac{q_0 G^2 MTF^2}{NPS}$$

DQE is independent of the detector technology and focuses only on its input and output signals. This way it can be used as a method of comparison of different imaging systems (a quantitative figure of merit).

DQE is a measure of image quality (high DQE = better the resolution of the img. system).

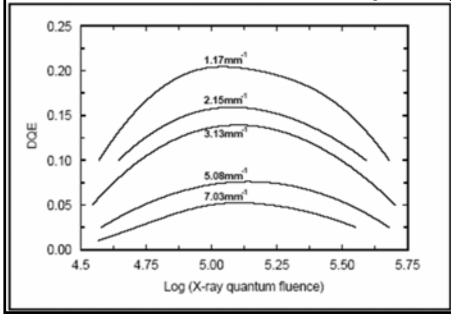
As with NEQ the DQE is often plotted against x-ray fluence;

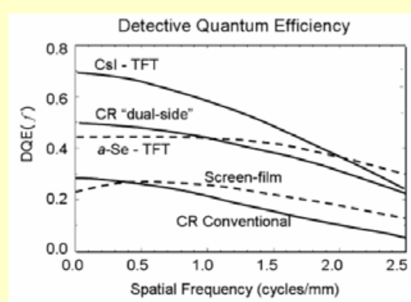
The figure below (left) is for the same screen-film system (shown in NEQ).

Obviously x-ray dose for this system is important for the image quality (hence under or over-exposed film provides a useless image). Also DQE drops quickly with increasing spatial frequency (most noise is at high spatial frequency and affects more higher frequency signals).

The figure below (right) shows approximate DQE for various detectors.

The CsI detector has better DQE compared with a-Se detector (the worst being screen-film).

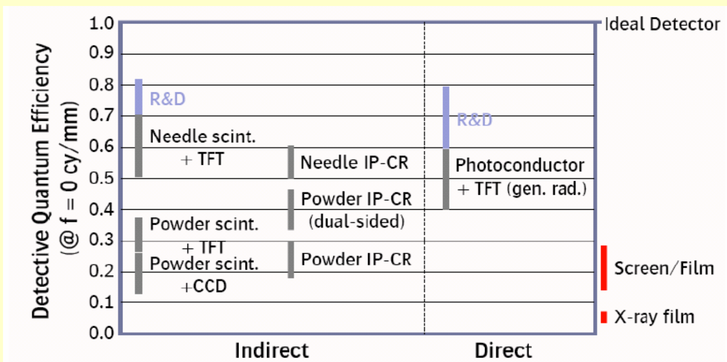




A detector that has a DQE value of twice that of another is said to be twice as efficient and therefore only requires half the amount of X-ray dose to produce an image with the same SNR.
Hence, in theory, the higher the DQE of the detector the lower the patient exposure dose.

Another general property of the DQE is that it increases with decreasing X-ray energy due to more efficient X-ray absorption at low kVp values. This reduction becomes less prominent for higher spatial frequencies. Contrast resolution for low-contrast details also improves with the DQE.

A problem of the DQE is that it describes only the detector (not the whole imaging system)



Current DQE values of direct and indirect digital systems and the current research areas

References:
M. Spahn. Flat Detectors and their Clinical Applications. European Journal of Radiology **15** 1934-1947 (2005)
Varian medical systems. www.varian.com. Online
Steven Evans Digital Imaging. Course notes
W Zhao, J Law, D Waechter, Z Huang and J Rowlands. Digital radiology using active matrix readout of amorphous selenium: Detectors with high voltage protection. Medical Physics **25 (4) (**1998)
S Webb. The Physics of Medical Imaging. IOP Publishing Ltd
D Darambara. Introduction to MTF, NPS, DQE. Course notes
J Dobbins, E Sarnei, N Ranger and Y Chen. Intercomparison of methods for image quality characterization. II. Noise Power Spectrum. Medical Physics **33 (5)** (2006)
K Faulkner and B Moores. Analysis of x-ray computed tomography images using the noise power spectrum and autocorrelation function. Physics in Medicine and Biology **29 (11)** (1984)
K Hanson. A simplified method of estimating noise power spectra. Physics of Medical Imaging 1998.
P Monnin, D Gutierrez, S Bulling, D Lepori, J-F Valley and F Verdun. A comparison of the performance of modern screen-film and digital mammography systems. Physics in Medicine and Biology **50** 2617-2631 (2005)
A Workman and D Brettle. Physical performance measures of radiographic imaging systems. Stockton Press 1997
S-A Starck, M Bath and S Carlsson. The use of detective quantum efficiency (DQE) in evaluating the performance of gamma camera systems. Physics in Medicine and Biology **50** 1601-1609 (2005)
R Schaetzing. A Comparison of Screen/Film and Digital Imaging: Image Processing, Image Quality and Dose. AGFA Coorporation. Online presentation
E Samei and M Flynn. An experimental comparison of detector performance for computed radiography systems. Medical Physics **29 (4)** 447-452 (2002)
C Schaefer-Prokop and M Prokop. Digital radiography of the chest: Comparison of the selenium detector with other imaging systems. Medicamundi **41 (1)** 1997.
J Seibert. Tradeoffs between image quality and dose. Pediatric Radiography **34** 183-195 (2004)
http://www.kcare.co.uk/Education/glossary.htm#glossaryn
http://www.aapm.org/meetings/99AM/pdf/2798-87374.pdf
http://www.gehealthcare.com/inen/rad/xr/education/dig_xray_iq.html